Flow control over a tractor-trailer using vortex generator

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1. INTRODUCTION

Lorries play a major role in daily domestic freight transportation within the UK. About 73.5% of domestic freight was moved by lorries within the UK in 2014 (1). In terms of emissions, in 2013, Heavy Goods Vehicles (HGV) contribute 13% or 15.5 million tonnes of transport related greenhouse gas emission in the UK [1]. Due to the fact that all HGVs have considerably blunt shapes, they encounter high level of aerodynamic drag during high speed operations. This in turn leads to high fuel consumption and severe issue in greenhouse gas emissions. In fact, Bradley [2] shows that the aerodynamic drag acting on a HGV operating at 66 mph accounts for approximately 21% of fuel consumption.

One of the most common ways to achieve drag reduction is by incorporating various flow control devices into HGVs. A flow control device aims to modify the flow pattern over an object. There are many flow control devices particularly designed for achieving drag reduction at different locations in HGVs such as the side extenders, cab deflectors, boat tails and blowing jets, to name a few. The effects of these devices on HGV drag reduction have been extensively studied in the past two decades [3]. However, it seems that the flow control effect provided by vortex generators is currently being overlooked in HGV related research. Vortex generators work on the principle of flow mixing enhancement in order to delay flow separation and therefore, to achieve form drag reduction. In fact, promising results have been obtained in achieving flow control using vortex generator in backward facing steps [4]. The aim of this study is to investigate experimentally whether vortex generators could also be applied to square back heavy vehicles in achieving flow control.

2. EXPERIMENTAL SETUP AND FLOW DIAGNOSTICS

A 1:20 scale generic tractor-trailer model was used in this experimental study. The length, width and height of the model are 714.38 mm, 125 mm and 172.48 mm respectively. A similar scale model was also used in by Taubert and Wygnanski [5]. The flow Reynolds number with respect to the height of the tractor model (Re_H) is $Re_H = 5.3x10^5$. With this flow Reynolds number, flow features generated along the tractor-trailer model are comparable to those generated by actual heavy vehicles [3]. Two vane type vortex generators (hereafter: VG) were used in this study. These two VGs have the same general shape but with different vane height and separation distance. The vortex generators were installed at various locations on the roof of the trailer model to investigate the size and location effects of the VGs.

Experiments were conducted in the de Haviland wind tunnel of the University of Glasgow. The wind tunnel has a 4.0 m x 2.7 m x 2.1 m (length x width x height) test section. Optical access to the wind tunnel test section is achieved through the two side windows and two ceiling mounted top windows. The tractor-trailer model was mounted on a stationary false floor in a way such that the wheels of the model were 2 mm above the surface of the false table. Similar experimental setup was also employed by Taubert and Wygnanski [5]. Currently only smoke visualisation was used for flow diagnostics.

3. PRELIMINARY RESULTS

Preliminary results obtained from the smoke visualisation experiment along the centerline of the tractor-trailer model with and without vortex generators installed were presented in Fig. 1.

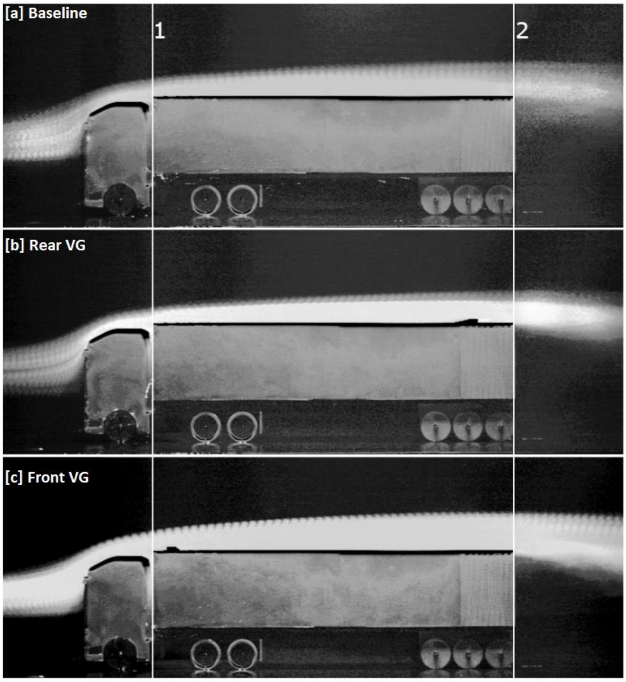

Figure 1 – Smoke visualisation images of the [a] Baseline model, model equipped with VG at the [b] back and [c] front of the trailer

From Fig. 1, it can be seen that the general flow pattern of the tractor-trailer model remains similar in both the baseline model (Fig. 1 [a]) and the model equipped with vortex generator at the back (Fig. 1

[b]) and front (Fig. 1 [c]) of the trailer model. In all cases, as seen in Fig. 1, a stagnation point appears at the front of the tractor model and the flow above the stagnation point turns upwards so that it reaches the top of the tractor model. The curvature leads to the expansion and acceleration of flow along the roof of the tractor. The flow then separated from the rear end (vertical line 1 in Fig. 1) of the tractor model and part of the flow entered the gap between the tractor and the trailer.

Across the gap, the size of the stream tube becomes progressively thicker along the trailer model. Flow separation appears at the rear end (vertical line 2 in Fig. 1) of the trailer model. This leads to the formation of a shear layer downstream of the trailing edge of the trailer. From Fig. 1, it can be seen that the shear layer angle in the three cases being studied is different. The shear layer points the most downwards in the case when the vortex generator is placed at the front of the trailer (Fig. 1 [c]) while the least downwards in the baseline model (Fig. 1 [a]). Qualitatively, in order to study the effects of the vortex generators on flow separation control, the thickness and angle of the stream tube at various locations along the trailer model as shown in Fig. 2 are measured. The average result obtained from 1000 measurements is tabulated in Table 1.

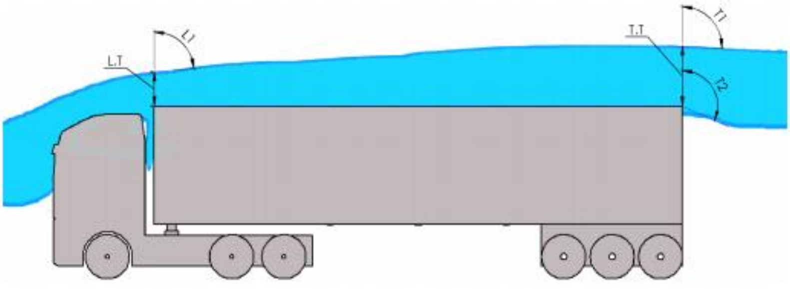

Figure 2 – Thickness and angle definition

Table 1 – Result of stream tube thickness and angle measurements

Case	L.T. (mm)	T.T. (mm)	L1 (deg)	T1 (deg)	T2 (Deg)
Baseline	31.55	58.53	84.60	91.14	97.91
Rear VG	N/A	55.72	N/A	91.39	99.28
Front VG	30.62	50.11	83.57	91.12	104.75

From Table 1, an interesting phenomenon can be observed. Amongst the three cases being studied, the shear layer angle (T2) is the highest (i.e. more downwards) when the vortex generator is installed at the front of the trailer. The baseline model shows the smallest shear layer angle. The result indicates that vortex generator could show effect in affecting the shear layer angle. Therefore, it is deduced that vortex generators may be able to alter the vortical structures in the wake region.

In fact, by injecting smoke at the rear end of the trailer, the vortical structure in the wake region can be observed and it is shown in Fig. 3. The diameter of the vortex core of the baseline model, the model equipped with vortex generator at the rear and front of the trailer is measured. The size of the vortex core for the baseline (Fig. 3 [a]), VG installed at the rear (Fig. 3 [b]) and front of the trailer (Fig. 3 [c]) is 60.42 mm, 53.19 mm and 48.72 mm, respectively. This indicates that the wake region is the smallest in the model equipped with vortex generator at the front of the trailer. This also proposed that vortex generators may be applicable to achieve flow separation control in square back heavy vehicles.

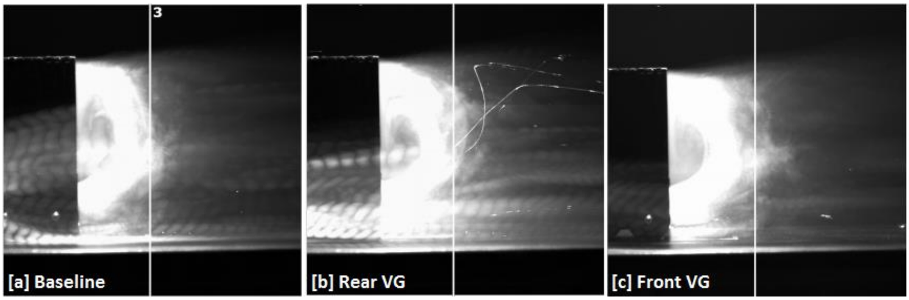

Figure 3 – Vortical structure of the wake region

4. FUTURE WORK

Particle Image Velocimetry (PIV) will be employed in order to obtain qualitative information along the flow field. Surface oil flow visualisation will also be used for providing qualitative information about the spanwise flow pattern along the tractor-trailer model.

5. REFERENCE LIST

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